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Method and Apparatus for Generating Non-Recursive Variable Rate Orthogonal Spreading Codes

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to communication systems and, more particularly, to non-recursively generating variable rate orthogonal spreading codes that are optimized for a multi-user, multi-rate environment.

2. Prior Art

In the forward direction of a Code Division, Multiple Access (CDMA) system, i.e., from a base station or base unit to a subscriber unit, it is relatively easy to synchronize the pseudo-noise (PN) codes of the various channels, since they are all created at and transmitted from the same base station. It is furthermore very easy to time-align the chips and symbols of the constituent signals within the aggregate waveform. As a result, the forward channel of most CDMA systems utilizes some form of synchronous CDMA. In some systems, such as a fixed wireless local loop telephone system known as Primewave 2000™ available from the assignee of this patent application, the reverse channel (i.e., subscriber unit to base station) is also quasi-synchronous. In this type of system, a timing control loop is utilized to maintain the various users in the system time-aligned such that their respective signals all arrive at the base station within a small fraction of a chip of each other.

Whenever synchronous or quasi-synchronous CDMA is employed, it becomes possible to use PN codes that are

designed to have the smallest possible cross-correlation when time-aligned with each other. If the number of users in the system is less than the number of chips transmitted for each channel symbol (which may be referred to as the channel symbol processing gain), then it is possible to design PN codes that are truly orthogonal to each other. When the number of users exceeds the channel symbol processing gain, then it is no longer possible to design codes that are orthogonal, since the dimensionality of the signaling space has been exceeded. For this reason, it is possible for synchronous and quasi-synchronous CDMA systems to support a number of users equal to the channel symbol processing gain, as long as the links have adequately large power and adequately low interference resulting from distortions such as clipping, multi-path, filtering and timing offsets.

It is often desirable for the system to support users that are not all at the same signaling rate. For example, in a system where some users are using a telephone and the required data rate is on the order of a few thousand bits per second (Kbps) to a few tens of Kbps, while other users are using the system as a computer network interface and require a million bits per second (Mbps) or more, the waveform should to be able to simultaneously accommodate the various non-homogeneous users.

It is possible to support a high rate user by allocating to him or her a plurality of parallel, lower rate channels, but this approach requires that the high rate users have a plurality of transmitters and receivers. As

such, this approach is less than desirable in many systems where cost is an important consideration.

A more cost-effective technique to support high rate and low rate users simultaneously is to employ a common chipping rate for all users, but to permit the users in the system to vary their channel symbol processing gains depending on their respective data rate. This implies that if one desires that all users in either the forward, or the forward and reverse channels, to be orthogonal to each other, independent of their rates, then a set of PN codes are needed of various lengths, and that are mutually orthogonal when synchronized appropriately.

Walsh functions are a set of binary and orthogonal waveforms that can be used for signal multiplexing purposes, and have long been recognized as having application to telephony. Reference in this regard can be had to an article entitled "The Multiplexing of Telephone Signals by Walsh Functions", by I. A. Davidson in Applications of Walsh Functions, 1971 proceedings, Second Edition, Eds. R. W. Zeek and A. E. Showalter, pages 177-179.

Of the number of possible sets of orthogonal functions that can be used as carriers in multiplex transmission, the category of the completely orthogonal Hadamard functions have also been long recognized as being particularly well suited for technical applications, including telephony applications. In general, Walsh functions are special Hadamard functions, and can be described by Hadamard matrices with powers of 2 as ordinary numbers. Further function systems can be derived

from Hadamard matrices by permutation of columns and rows and by sign inversion, while preserving their orthogonal characteristics.

One method for creating PN codes which are mutually orthogonal is to use a recursive construction technique defined by H. Hubner, "Multiplex Systems Using Sums of Walsh Functions as Carriers", also in Applications of Walsh Functions, 1971 proceedings, Second Edition, pages 180-191.

Reference in this regard can also be had to U.S. Pat. No. 5,571,761, entitled "System and Method for Orthogonal Spread Spectrum Sequence Generation in Variable Data Rate Systems", by Klein S. Gilhousen.

In general, the approach used in U.S. Pat. No. 5,751,761 is a recursive approach, wherein the value of the nth output of y is created from a previous value of y, so long as n>0. In other words, past relationships are used to create new, current relationships between code elements resulting in a tree like code structure as shown in Gilhousen.

However, there are several problems with the approach described in U.S. Pat. No. 5,751,761. First, if the Walsh codes were used directly then the spectral properties of the PN codes would be very poor. This is due to the fact that the codes are made up of very regular patterns. Some codes are completely un-spread, while others are spread with square waves whose frequencies are one, two, four, eight, etc. times the symbol rate. These users would have very limited immunity to jammers, and would not gain the

benefits of being spread with a PN code of processing gain n or 2n (depending on their rate).

In U.S. Pat. No. 5,751,761, the approach used to avoid this problem is to apply a cover code to the code matrix. This amounts to multiplying every code in the set by a single randomizing vector of ±1-valued chips whose length is much larger than the channel symbol processing gain. So long as every code in the set is multiplied by the same cover code, the orthogonality of the set is retained, but the resulting set is made to appear more random.

However, a problem that arises when applying a cover code to the matrix is that the resulting randomized Walsh codes are not uniform. This means that, over any symbol or spreading period, the number of +1 valued chips and -1 valued chips are not equal to one another in most of the resulting PN codes. Balance in the code set is a very desirable property, since it implies that the codes are orthogonal to any DC offset in the receiver of the signal. In other words, if the chips are ±1 millivolts in the receiver, but there is a 2 millivolt DC offset in the signal at the input of the despreader, then the despreader would have to multiply the ±1 despreading code with an input signal having values of +3 and +1 millivolts. However, if the PN code is over a symbol, then the DC offset will not affect the despreading process.

Another problem associated with using code sets that are recursively generated is that code sets so generated are not orthogonal if linearly related. In addition, even

code sets that are not linearly related but are derived from the same node are orthogonal but only over some predetermined time period. In other words, the instantaneous cross-correlation between code sets of the same branch may be relatively high which results in interference between users. It will further be appreciated by those skilled in the art that the closer the code sets are to the root node the higher the instantaneous cross-correlation.

As has been made apparent, the use of recursive techniques to create PN code sets can result in non-orthogonal and orthogonal codes that exhibit high instantaneous cross-correlation.

SUMMARY OF THE INVENTION

The foregoing and other problems are overcome, and other advantages are realized, in accordance with the presently preferred embodiments of these teachings.

In accordance with one embodiment, a method for selecting non-recursive variable rate spreading codes is provided. The method includes providing a plurality of symmetrical spreading code sets C_1, $C_2 \ldots C_n$; and selecting one of the plurality of symmetrical spreading code sets C_1, $C_2 \ldots C_n$ according to a predetermined dwell time.

In accordance with another embodiment, a non-recursive method for constructing orthogonal PN code sets for use in a code division, multiple access (CDMA) communication system is provided. The method includes forming a first modulation matrix M^1, wherein the first modulation matrix

M^1 includes at least one modulation vector $M_{1...k}$, where k is predetermined and forming a first base-code matrix C, wherein the first base-code matrix C includes sub-base code matrices C^r, where $r \geq 2$. From these matrices PN code sets are formed according to:

$\ldots\ C^1_{i,:}\ M_{j,1}\ C^2_{i,:}\ M_{j,2}\ \ldots\ C^r_{i,:}\ M_{j,r}\ C^1_{i,:}\ M_{j,r+1}\ \ldots\ C^w_{i,:}\ M_{j,k}\ C^{w+1}_{i,:}\ M_{i,1}\ \ldots$, where i = i^{th} row; subscript ":" = all columns within the i^{th} row; and $k > r$.

The method of forming the first modulation matrix M^1 further includes providing P modified-Hadamard matrices G_i^P with dimension $2^{(B-1)}SF_{min}$ x $2^{(B-1)}SF_{min}$, where P=1...B, $B=Sf_{max}/SF_{min}$. The P modified-Hadamard matrices are constructed from a Hadamard matrix using row/column permutations as well as row inversions by permuting the rows of the P Hadamard matrix(s) in accordance with at least one first predetermined formula, permuting the columns of the P Hadamard matrix(s) in accordance with at least one second predetermined formula, and inverting a subset of the rows of the P Hadamard matrix(s) in accordance with at least one third predetermined formula.

In accordance with another embodiment, the invention is directed towards a program storage device readable by a machine, and tangibly embodying a program of instructions executable by the machine to perform a method for selecting non-recursive variable rate spreading codes. The method includes providing a plurality of symmetrical spreading code sets C_1, $C_2 \ldots C_n$; and selecting one of the plurality of symmetrical spreading code sets C_1, $C_2 \ldots C_n$.

In accordance with another embodiment a program storage device readable by a machine, tangibly embodying a

program of instructions executable by the machine to perform method steps for constructing and selecting orthogonal PN code sets for use in a code division, multiple access (CDMA) communication system is provided. The method includes the steps of forming a first modulation matrix M^1, wherein the first modulation matrix M^1 includes at least one modulation vector $M_{1 \ldots k}$, where k is predetermined and forming a first base-code matrix C, wherein the first base-code matrix C includes sub-base code matrices C^r, where $r \geq 2$. From these matrices PN code sets are formed according to:… $C^1_{i,:}\ M_{j,1}\ C^2_{i,:}\ M_{j,2} \ldots C^r_{i,:}\ M_{j,r}\ C^1_{i,:}\ M_{j,r+1} \ldots C^w_{i,:}\ M_{j,k}\ C^{w+1}_{i,:}\ M_{i,1} \ldots$, where $i = i^{th}$ row; subscript ":" = all columns within i^{th} row; and $k > r$.

In accordance with another embodiment a substantially synchronous CDMA communications system is provided. The system includes a radio base unit capable of bi-directional wireless multirate communications with a plurality of subscriber units. Each subscriber unit has a subscriber unit data rate and a controller for reordering a Hadamard matrix by exchanging columns and rows of the first Hadamard matrix in accordance with at least one first predetermined reordering code to produce a first reordered pseudonoise (PN) code set having improved spectral properties. The controller also reorders at least two second Hadamard matrices by exchanging columns and rows of each of the second Hadamard matrices in accordance with at least one second predetermined reordering code to produce at least two second reordered pseudonoise (PN) code sets. Also provided is a modulator for modulating the first reordered PN code set with each of the second PN code sets to generate at least two usable PN code sets for modulating a data signal of the

subscriber units as a function of the subscriber unit data rate.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects and other features of the present invention are explained in the following description, taken in connection with the accompanying drawings, wherein:

Figure 1 is a block diagram of a communications system implementing features of the present invention;

Figure 2 is a flow chart of one method for implementing features of the present invention as shown in Figure 1;

Figure 3 is heterodyne spreading system implementing features of the present invention shown in Figure 1;

Figure 4 is a homodyne spreading system implementing features of the present invention shown in Figure 1;

Figure 5 is a relationship diagram between one set of non-recursive spreading codes in a variable rate environment;

Figure 6 is a table showing blocked nodes for each active node in Figure 5, at different symbol rates; and

Figure 7 is a multi-relationship diagram between multiple sets of non-recursive spreading codes in a variable rate environment, and showing dwell times $t_1 \ldots t_n$, for each set.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Figure 1, there is shown pictorial diagram of a multi-user telecommunications system incorporating features of the present invention. Although the present invention will be described with reference to the embodiment shown in the drawings, it should be understood that the present invention could be embodied in many alternate forms of embodiments.

Still referring to Figure 1 there is shown a Fixed Wireless System (FWS) 10 that is suitable for practicing this invention. Specifically, the FWS 10 employs direct sequence spread spectrum based CDMA techniques over an air link to provide local access to subscribers, and offers very high quality, highly reliable service. The FWS 10 is a synchronous CDMA (S-CDMA) communications system wherein forward link (FL) transmissions from a base station, referred to also as a radio base unit (RBU) 12, for a plurality of transceiver units, referred to herein as user or subscriber units (SUs) 14, are symbol and chip aligned in time, and wherein the SUs 14 operate to receive the FL transmissions and to synchronize to one of the transmissions. Each SU 14 also transmits a signal on a reverse link (RL) to RBU 12 in order to synchronize the timing of its transmissions to the RBU 12, and to generally perform bi-directional communications. The FWS 10 is suitable for use in implementing a telecommunications system that conveys multirate voice and/or data between the RBU 12 and the SUs 14.

The RBU 12 includes circuitry for generating a plurality of user signals ($USER_1$ to $USER_n$), which are not shown in

FIGURE 1, and a synchronous side channel ($SIDE_{chan}$) signal that is continuously transmitted. Each of these signals is assigned a respective PN spreading code and is modulated therewith before being applied to a transmitter 12a having an antenna 12b. When transmitted on the FL the transmissions are modulated in phase quadrature, and the SUs 14 are assumed to include suitable phase demodulators for deriving in-phase (I) and quadrature (Q) components there from. The RBU 12 is capable of transmitting a plurality of frequency channels. By example, each frequency channel includes up to 128 code channels, and has a center frequency in the range of 2 GHz to 4 GHz.

The RBU 12 also includes a receiver 12c having an output coupled to a side channel receiver 12d. The side channel receiver 12d receives as inputs the spread signal from the receiver 12c, a scale factor signal, and a side channel despread PN code. These latter two signals are sourced from a RBU processor or controller 12e. The scale factor signal can be fixed, or can be made adaptive as a function of the number of SUs 14 that are transmitting on the reverse channel. The side channel receiver 12d outputs a detect/not detect signal to the RBU controller 12e for indicating a detection of a transmission from one of the SUs 14, and also outputs a power estimate value. A read/write memory (MEM) 12f is bi-directionally coupled to the RBU controller 12e for storing system parameters and other information, such as SU timing phase information and power estimate values.

A Network Interface Unit (NIU) 13 connects the RBU 12 to the public network, such as the public switched telephone network (PSTN) 13a, through analog or digital trunks that

are suitable for use with the local public network. The RBU 12 connects to the NIU 13 using E1 trunks and to its master antenna 12b using a coaxial cable. The SU 14 communicates with the RBU 12 via the radio interface, as described above.

In the illustrated embodiment the SU-RBU air link provides a separate 2.72 MHz (3.5 MHz including guard bands) channel in each direction separated by 91 MHz, 100 MHz, or 119 MHz of bandwidth. The nominal spectrum of operation is 2.1-2.3 GHz, 2.5-2.7 GHz, 3.4-3.6 GHz, or 3.5-3.7 GHz. However, the system is adaptable such that the frequency can be varied as required. As will be made evident below, it is not necessary that the RBUs 12 be synchronized to one another, when employing orthogonal, variable spread factor spreading (OVSF) code sets in accordance with this invention.

An OVSF code set can be described by a matrix M having dimension SF_{max} x SF_{max} where SF_{max} is the maximum desired spreading factor measured in chips/symbol and a spreading code is a row of the matrix M. Changing the number of chips per symbol (e.g. spreading factor) varies the information symbol rate of the CDMA channel. For example, a chipping rate of 3.84 Mcps could support an information symbol rate of 30 ksps with a spreading factor of 128 chips/symbol and an information symbol rate of 60 ksps with a spreading factor of 64 chips/symbol. With a fixed chipping rate, varying the spread factor does not change the RF bandwidth of the transmitted DS-CDMA waveform, only the capacity measured in information bits or symbols per second.

When properly assigned, OVSF codes have the property that all users, regardless of the data modulation and spread factor (and CDMA channel rate), are preferably orthogonal or nearly orthogonal such that the cross-correlation between codes is acceptable.

Referring now to Figure 2 there is shown an example of one method for the construction of OVSF codes incorporating features of the present invention. In this example the construction requires $n=\log_2(B)$ steps where $B=SF_{max}/SF_{min}$ and SF_{min} and SF_{max} equals the minimum and maximum desired spreading factors, respectively, and B is restricted to a power of two.

The first step 21 forms the B sub-matrices G_i^1 with dimension SF_{min} x SF_{min}. The G_i^1's are constructed from a Hadamard matrix using row/column permutations as well as row inversions. Using a pseudo code this process can be described as:

```
H = hadamard(SFmin);     % Start with a Hadamard matrix of size SFmin x SFmin

% Generate basis matrices (e.g. Step 1)
for i=1:B,
    [x,cp] = sort( rand(1,SFmin) );
    H1 = H(:,cp);                          % Column permutation

    [x,rp] = sort( rand(1,SFmin) );
    H2 = H1(rp,:);                         % Row permutation

    x = (-1).^( rand(1,SFmin) > 0.5 );
    for k=1:SFmin,
        H3(k,:) = x(k) * H2(k,:);
    end                                    % Row inversion
    G(i).G = H3;                           % Store basis matrix
end
```

The next step 22 pseudo-randomly generates B/2 random, binary values $a_{2,i}$ with $1 \le i < B/2$ and forms the constituent

B/2 sub-matrices G_i^2 with dimension 2 SF_{min} x 2 SF_{min}. For i ranging from 1 to B/2, the G_i^2's are constructed as:

$$G_i^2 = \begin{cases} \begin{bmatrix} G_{2i-1}^1 & G_{2i}^1 \\ -1 \cdot G_{2i-1}^1 & G_{2i}^1 \end{bmatrix} & if \quad a_{2,i} = 1 \\ \begin{bmatrix} G_{2i-1}^1 & G_{2i}^1 \\ G_{2i-1}^1 & -1 \cdot G_{2i}^1 \end{bmatrix} & else \end{cases}$$

Step 22 is repeated as necessary to generate the required constituent matrices. For example, pseudo-randomly generate B/4 random matrices, binary values $a_{3,i}$ with $1 \le i < B/4$. Form B/4 sub-matrices G_i^3 with dimension 4SF_{min} x 4SF_{min}. For I ranging from 1 to B/4, the G_i^3's are constructed as:

$$G_i^3 = \begin{cases} \begin{bmatrix} G_{2i-1}^3 & G_{2i}^3 \\ -1 \cdot G_{2i-1}^3 & G_{2i}^3 \end{bmatrix} & if \quad a_{3,i} = 1 \\ \begin{bmatrix} G_{2i-1}^3 & G_{2i}^3 \\ G_{2i-1}^3 & -1 \cdot G_{2i}^3 \end{bmatrix} & else \end{cases}$$

The last generation of the constituent matrices, step 22, may be stated as pseudo-randomly generating one random, binary value $a_{n,1}$ with $1 \le i < 2$ and forming the matrix G_1^n with dimension SF_{max} x SF_{max}. The final matrix G_1^n is the OVSF code set (M) and is constructed as:

$$M = G_1^n = \begin{cases} \begin{bmatrix} G_1^{n-1} & G_2^{n-1} \\ -1 \cdot G_1^{n-1} & G_2^{n-1} \end{bmatrix} & if \quad a_{n,1} = 1 \\ \begin{bmatrix} G_1^{n-1} & G_2^{n-1} \\ G_1^{n-1} & -1 \cdot G_2^{n-1} \end{bmatrix} & else \end{cases}$$

It will be appreciated that the matrix M has all the properties of an OVSF code set as described above. Using pseudo code step 22 can be described as:

```
% Generate constituent matrices (e.g. Steps 2-n)
L = B/2;                                  % Number of binary variables
while L >= 1,
    a = rand(1,L) > 0.5;                  % Generate the binary variables
    for l=1:L,                            % For each variable
        G1 = G(2*l-1).G;                  % Get the constituent matrices
        G2 = G(2*l).G;
        a1 = (-1)^a(l);
        a2 = -1*a1;
        G(l).G = [    G1     G2
                   a1*G1 a2*G2];          % Form and store the new matrix
    end
    L = L/2;
end
% Store the OVSF set
M = G(1).G;
```

Steps 23-26 test the properties of the rows (spreading codes) of the resulting constituent matrices. Using a pseudo code this process can be described as:

```
% Test OVSF Properties:
test_flag = 0;
SF = SFmin;                     % Start with spread factor SFmin
while SF <= SFmax,
    A = M(1:SF,:);              % Get the first L rows of M
    for k=1:SFmax/SF,
        i1 = (k-1)*SF+1;        % Lower column index
        i2 = i1+SF-1;           % Upper column index
        B = A(:,i1:i2);         % Form sub-matrices using L columns of A
        c = sum(sum(( B * B' - SF*eye(SF))));    % Check for orthogonality
        test_flag = c ~= 0;     % set error flag
    end
    SF = 2 * SF;                % move to next spread factor
end

if test_flag==0
    disp('passed the test');
end
```

The following example shows the construction of the PN code sets for a variable-rate, orthogonal spreading codes. The construction begins with a 16 x 16 Hadamard matrix (H). Using row/column permutations and row inversions (e.g. multiplication by -1) of H, three 16 x 16 base code sub-matrices (H_1, H_2 and H_3) are formed. These three 16x16 matrices are concatenated to form a 16

x 48 base code matrix C = [H_1 | H_2 | H_3]. Next, an 8 x 8 modulation matrix M is constructed with M being an OVSF code set (SF_{max}=8). Using the new method proposed herein, the construction begins with a 2x2 Hadamard matrix H (e.g. SF_{min} = 2 and B=4). To construct M, four, 2x2 matrices G_1^1, G_2^1, G_3^1, and G_4^1 are constructed using row/column permutations and row inversions of H. Using the four 2x2 matrices, two 4x4 matrices G_1^2 and G_2^2 are formed using Step 2. The modulation matrix M is formed using G_1^1 and G_1^1 as:

$$M = \begin{cases} \begin{bmatrix} G_1^2 & G_2^2 \\ -1\cdot G_1^2 & G_2^2 \end{bmatrix} & if \quad a_{3,1} = 1 \\ \begin{bmatrix} G_1^2 & G_2^2 \\ G_1^2 & -1\cdot G_2^2 \end{bmatrix} & else \end{cases}$$

With this construction, the modulation matrix has the following properties:

1. Row k=0 of M is pair-wise orthogonal with all **odd** indexed rows:

$$\sum_{i=0}^{1} m_0(i+2K)\cdot m_{2j+1}(i+2K) = 0 \quad K = 0,\ldots,3 \quad j = 0,\ldots,3$$

2. Row k=1 of M is pair-wise orthogonal with all **even** indexed rows:

$$\sum_{i=0}^{1} m_1(i+2K)\cdot m_{2j}(i+2K) = 0 \quad K = 1,\ldots,4 \quad j = 0,\ldots,3$$

3. Rows 0 and 2 of M are four-wise orthogonal with all **odd** indexed rows:

$$\sum_{i=0}^{1} m_n(i+2K)\cdot m_{2j+1}(i+2K) = 0 \quad K = 0,\ldots,3 \quad j = 1,\ldots,4 \quad n = 0,2$$

4. Rows 1 and 3 of M are four-wise orthogonal with all **even** indexed row

$$\sum_{i=0}^{1} m_n(i+2K)\cdot m_{2j}(i+2K) = 0 \quad K = 0,\ldots,3 \quad j = 0,\ldots,3 \quad n = 1,3$$

5. The rows of M are eight-wise orthogonal:

$$\sum_{i=0}^{7} m_n(i) \cdot m_k(i) = 0 \quad \forall n \neq k \quad 0 \leq n,k < 7$$

The construction of the modulation matrix allows for the variable rate operation of the spreading codes in a heterodyne spreading system as shown in Figure 3. Here, a 1 x 8 row of the modulation matrix, termed a *modulation spreading vector*, is chosen to perform spreading at a rate or R_c / 16. Following the outer spreading, a 1 x 48 row of the base code matrix, termed a *base code-spreading vector*, is chosen to perform spreading at a rate of R_c. For continuous spreading, the modulation spreading vector and the base code spreading vectors are repeated in a cyclic fashion.

As shown in Figure 3, each element of a modulation-spreading vector M_k is spread by spreader 32 using 16 chips from the base code-spreading vector C_k to form an aggregate spreading sequence R_c. The aggregate spreading sequence R_c then spreads the complex data stream R_s in spreader 31. In an alternative embodiment, heterodyne spreading may be implemented as shown in Figure 4. The complex data stream R_s has been spread by spreader 41 with a M_k vector with a spread factor of 1, 2, 4 or 8 chips per symbol depending on the input symbol rate (R_s). At spreader 42 the complex data stream is spread again with a spread factor of 1, 16, 32, 64 or 128 chips per symbol again depending on the input symbol rate (R_s) and forms the complex spread data stream R_c. Recall, the input symbol rate R_s can take on values of R_c, $R_c/16$, $R_c/32$, $R_c/64$ and $R_c/128$.

The C and M matrices are constructed for the variable rate spreading codes as follows. For each row of the base code matrix (C), form one spreading code at SF=16, two spreading codes at SF=32, four spreading codes at SF=64 and eight spreading codes at SF=128. In Figure 5, there is shown one appropriate modulation matrix row index for the construction of the variable rate spreading codes for an arbitrary base code index (n). As can be seen, the allowable spreading code index pairs (n,k) follow the following rules:

1. If $R_s=R_c/16$ (e.g. SF=16), then k=0
2. If $R_s=R_c/32$ (e.g. SF=32), then k=0 or 1
3. If $R_s=R_c/64$ (e.g. SF=64), then k=0, 1, 2 or 3
4. If $R_s=R_c/128$ (e.g. SF=128), then k=0,1,…, or 7

Still referring to Figure 5, the tree structure for visualizing the allocation of the variable rate spreading codes is shown. The rules above show the allowable k values which should be used at each symbol rate. The tree 51 illustrates the rules regarding allowable k values in the presence of existing CDMA channels. For terminology, a CDMA channel with spreading code index pair (n,k) and symbol rate Rs can be considered a node N on the tree 51. When a channel is active, the node is active. For each active node, other nodes are "blocked" and may not be used. Figure 6 shows the "blocked nodes" for each "active node" in the spreading code tree for the different symbol rates.

Referring also to Figure 7 there is shown a preferred embodiment of the present invention. Here there are shown PN trees $T_1 \ldots T_n$, where each PN tree is constructed as

above. As shown, each PN tree $T_1 \ldots T_n$ is associated with a dwell time $t_1 \ldots t_n$. The dwell times may be equal in duration and set to a symbol time or rate of a specific user. In alternate embodiments the dwell times $t_1 \ldots t_n$ may each be different and pseudo randomly determined. For example, dwell time t_1 may be an integer multiple of the lowest symbol rate while dwell times t_2 and t_n may be integer multiples of the highest and intermediate symbol rates, respectively.

A specific example of the more general case presented here was presented earlier in U.S. Patent 6,091,760, incorporated here by reference in its entirety. It was noted in that patent that OVSF code sets may be constructed by performing constrained permutations on the OVSF code set constructed via Hadamard construction. For example, let M be an SF_{max} x SF_{max} Hadamard set (which is also an OVSF set). For a minimum spread factor of SF_{min} and a maximum spread factor of SF_{max} with $B = SF_{max} / SF_{min}$, the method presented in U.S. Patent 6,091,760 proceeds as follows:

Step 1: Begin with an SF_{max} x SF_{max} Hadamard matrix or inverted (e.g. multiplication by –1) Hadamard matrix H.

Step 2: Form sub-matrices G_i^1 by grouping SF_{min} columns of H as

$$M_1 = \left[G_1^1 \mid G_2^1 \mid \cdots \mid G_B^1\right]$$

Step 3: Form matrices G_i^2 by column-wise permutations of G_i^1 with

$$M_2 = \left[G_1^2 \mid G_2^2 \mid \cdots \mid G_B^2\right]$$

Step 4: Form permutation groups from the matrices as $(G_1^2, G_2^2), (G_3^2, G_4^2), \cdots, (G_{B-1}^2, G_B^2)$ and permute with:

$$\begin{aligned} M_3 &= \left[(G_1^2, G_2^2) \mid (G_3^2, G_4^2) \mid \cdots \mid (G_{B-1}^2, G_B^2) \right] \\ &= \left[G_1^3 \mid G_2^3 \mid \cdots \mid G_B^3 \right] \end{aligned}$$

Step 5: Form permutation groups from the matrices as $(G_1^3 G_2^3, G_3^3 G_4^3), \cdots, (G_{B-3}^3 G_{B-2}^3, G_{B-1}^3 G_B^3)$ and permute with:

$$\begin{aligned} M_4 &= \left[(G_1^3 G_2^3, G_3^3 G_4^3) \mid \cdots \mid (G_{B-3}^3 G_{B-2}^3, G_{B-1}^3 G_B^3) \right] \\ &= \left[G_1^4 \mid G_2^4 \mid \cdots \mid G_B^4 \right] \end{aligned}$$

Step n: Form a permutation group $(G_1^{n-1} \ldots G_{B/2}^{n-1}, G_{B/2+1}^{n-1} \ldots G_B^{n-1})$ and permute with:

$$\begin{aligned} M_n &= \left[(G_1^{n-1} \ldots G_{B/2}^{n-1}, G_{B/2+1}^{n-1} \ldots G_B^{n-1}) \right] \\ &= \left[G_1^m \mid G_2^n \mid \cdots \mid G_B^n \right] \end{aligned}$$

Step n+1: The OVSF set M equals result of final permutation $M=M_n$ with M being a Hadamard matrix (e.g. $MM^T = nI$ where M is n x n).

As in the present preferred embodiment this specific example is also non-recursive in that the OVSF code set of size SF_{max} is not constructed from the OVSF code set of size $SF_{max}/2$ (e.g. $M_x \neq f(M_{x/2})$). Furthermore, the construction is capable of generating many OVSF code sets. To count the number of OVSF sets that may be constructed, it is noted that there are exactly $SF_{min}!$ column permutations of each of the sub-matrices G_i^1.

There are B such sub-matrices giving a total of $(SF_{min}!)^B$ possible values for M_2. In Step 4, there are a total of $2^{B/2}$ possible results from the permutations. In Step 5, there are a total of $2^{B/4}$ possible results from the permutations. In Step n, there are a total of 2^1 possible results from the permutations. Noting that the procedure may begin with either a Hadamard or inverted Hadamard matrix, the total number of OVSF codes constructed via the constrained permutation method is:

$$Codes\_permutation\_method = 2 \cdot (SF_{min}!)^B \cdot 2^{\left(\frac{B}{2}+\frac{B}{4}+\ldots+1\right)}$$

It will be appreciated that the special case of constrained permutation of the Hadamard matrix results in a lower total number of OVSF code sets. Recall that in Step 1, there are (Sfmin!) row permutations of the matrices and there are (Sfmin!) column permutations of the matrices. Thus, the size for the G matrix is lower bounded by (Sfmin!)2. When the row inversion is applied, there are a total of 2Sfmin possible inversions. However due to the structure of the Hadamard matrix, some elements may be duplicated. For example, a matrix generated by inverting row one with a given row/column permutation may also be generated using a different row/column permutation and inverting row 2.

However, in the more general method presented above, inverting all rows does not result in a duplicated matrix. Based on this, the alphabet size for the G can be bounded as:

$$2 \cdot (SF_{min}!)^2 \le \left\langle G_i^1 \right\rangle \le 2^{SF_{min}} \cdot (SF_{min}!)^2$$

In Step 2, there are B/2 binary values a2,I giving 2B/2 possibilities. In Step 3, there are B/4 binary values a3,I giving 2B/4 possibilities. In Step n, there is one binary value an,1 giving 2 possibilities. Based on this, the total number of OVSF codes constructed via the general method is lower bounded by:

$$Codes\_new\_method \geq 2 \cdot (SF_{\min}!)^{2B} \cdot 2^{\left(\frac{B}{2}+\frac{B}{4}+...+1\right)}$$

Comparing the number of codes generated the new approach versus the constrained permutation method; we find that the new approach generates more codes by a factor of:

$$\frac{Codes\_new\_method}{Codes\_permutation\_method} \geq (SF_{\min}!)^{B}$$

For every OVSF set generated by the constrained permutation method, there exists a SF_{min} x SF_{min} matrix $G_1^1 = G_2^1 = ... = G_B^1$ where G_1^1 is generated by only column permutations of H or -1H and a set of binary variables $a_{i,j}$, such that the same OVSF code set would be generated by the new method. The additional degree of freedom for the new method is found in the ability to perform row permutations and independent row inversions on the basis matrices G_i^1. Row permutation and row inversions increase the size of the set for the new method by at least a factor $(SF_{\min}!)^{B}$ of over the size of the set for the constrained permutation method.

Another example, requires the construction of an OVSF code set with SF_{min}=2 and SF_{max} = 8 for use as the modulation matrix. Using the constrained permutation

method, 256 different modulation matrices may be constructed. Using the general approach, at least 4096 OVSF sets may be constructed.

Based on the foregoing, in one aspect this invention provides a non-recursive technique for constructing a series of mutually orthogonal sets of PN codes which support multi-rate signaling and that each of the sets of PN codes are selected for a predetermined time duration such as integer multiple of a user symbol time. The sets of PN codes have the desirable properties that the constituent codes are at all of the desired symbol rates, and that furthermore the constituent codes exhibit desirable spectral properties.

Another aspect of this invention provides an improved technique for providing PN code structures for use in a CDMA communications system having a plurality of users simultaneously operating at different data rates or single data rates.

A further aspect of this invention provides a non-recursive technique for constructing a series of PN code sets that can be used to advantage in multi-rate synchronous and quasi-synchronous CDMA systems, wherein the technique employs a permuted orthogonal matrix to modulate permuted orthogonal matrices to create multiple PN code sets that support multi-rate operation and that the multiple PN code sets may be selected for a predetermined time duration such as a user symbol time.

It should be understood that the foregoing description is only illustrative of the invention. Various alternatives

and modifications can be devised by those skilled in the art without departing from the invention. Accordingly, the present invention is intended to embrace all such alternatives, modifications and variances that fall within the scope of the appended claims.